ANAEROBIC DIGESTION OF ALGAE

BY

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CERTIFICATE

This is to certify that the present work has been carried out by Shri Prem Adip Saini under my supervision and the work has not been submitted elsewhere for a degree.

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ABSTRACT

Oxidation pond is effective and economical treatment unit for treating sewage and wastes specially for tropical countries like India. Their use makes available algae in large amounts which normally is wasted by throwing in streams, losing an economical product as well as causing nuisance in streams. The present study was attempted to make use of this product to get economic benefits.

The study was divided in two parts namely harvesting the algae from oxidation pond effluents and its subsequent digestion anaerobically to get digester gas which can be used as a source of energy because of its high fuel value.

It was found out that autoflocculation and foam floation are suitable and cheap means of harvesting algae for anaerobic digestion, while alum coagulated algae is not suitable for digestion because of high alum content which goes with the algae in the digesters. 51% destruction in VM was obtained in 30 days detention time at a loading of 0.03 lbs/cft/day at 35°C. The gas yield was 7.0 cuft/lb of VM fed.

If for any community oxidation pond and anaerobic digesters are used in unision then the economic returns from the digester gas would be able to meet some of the maintenance and overhead charges for the waste treatment system.

CHAPTER I

INTRODUCTION

With the progress of civilization, the man's requirements for energy are also increasing in many folds. The increasing demands of energy coupled with the realization, that the fossil fuels and nuclear energy sources are going to be exhausted sooner or later, man is busy searching for other energy sources which can cater to his ever increasing demands. As it is very clear solar energy is available in plenty, having an intensity of 10,000 ft. candles. If effective means to trap it can be found, it can fulfil all the requirements. But there are a few factors which put limitations on its being used as an alternative source on a large scale. Some of them are intermittent supply, limited utility because of low concentrations in which it is available and problems of storage. These factors are taken care of to some extent in its conversion to chemical energy stored in the algae biomass in the oxidation ponds in which treatment of wastes is achieved through photosynthesis. In these ponds bacteria decompose organic constituents of the wastes and makes them available to algae. The algae by trapping solar energy in photosynthesis and minerals thus made available gives rise to more algal cells, as well as produce oxygen which is used by the bacteria to oxidize the wastes. In photosynthesis the efficiency of solar energy conversion to cellular material is only about 6%,

because this process becomes light saturated above 500 ft. candle light intensity. Also the energy that can be made use of is the one having wave length, between 4000 - 7000A^{o}, which comprises only 40% of the total sunlight(1). Because of these reasons it cannot be said that this method of making the solar energy available for the use of humanity is ultimately most efficient but still it shows us the way in this direction.

The practice currently involves disposal of the effluent from oxidation pond by either Seepage and evapotranspiration, or through stream disposal. These methods of disposal have their own limitations such as non-availability of vast expenses of land, non-availability of sufficiently big stream or the danger that stream disposal will cause to fish or other types of life in water depleting dissolved oxygen in the night. Besides these factors, the algae which is a useful product goes not only as a waste but also becomes a nuisance through increasing eutrophication of the stream.

The whole cell mass of microplants, algae, is nutritious as against higher plants which have about half or less of the total dry weight as nutritive portion. Algae contain 10 amino acids and large amounts of vitamins A,B,C (2,3). Some experiments are in progress regarding the use of algae as chicken and live stock feed(4). Though algae may not be suitable for human consumption

because of chemical additives and pathogens that come with this during removal, they can be used either to get economic returns in terms of increased agricultural yield by using this as fertilizer(5) or as fuel directly after drying. Fuel characteristics of dried algae are similar to those of medium grade bituminous coal although the heat content is some what lower ranging upto 10,000 Btu/lb.(3). It can also be subjected to anaerobic digestion, where its degradation by bacteria will give rise to digester gas which is mainly methane. The net fuel value of pure methane is 963 Btu/cft under standard conditions(6). Thus the methane rich digester gas could either be burnt in gas-turbine-generator system to produce electricity or can be used as a domestic fuel.

1.1 Objective of the Present Study

In tropical countries like India having long sunshine hours and high temp., the oxidation pond as treatment unit for waste are very effective and are being adopted widely. Because of this large amounts of algae are available, in the oxidation ponds effluent, which can become a good source of fuel after anaerobic digestion(7).

This study was carried out with this objective in view. It consists of two parts harvesting of algae and anaerobic digestion. In harvesting the emphasis was to find out a cheap and effective method. Following

methods were tried:

1. Auto flocculation

2. Foam floatation

3. Chemical coagulation

While in anaerobic digestion the objective was to find out:

1. Effect of temperature on digestibility of algae

2. Optimum loading of algae

3. Gas production per lb. algae fed

4. Extent of digestibility of algae

5. Effect of chemical, used in harvesting, upon digestibility.

6. Nutrient requirements for the digestion of algae.

Chapter 2

LITERATURE REVIEW

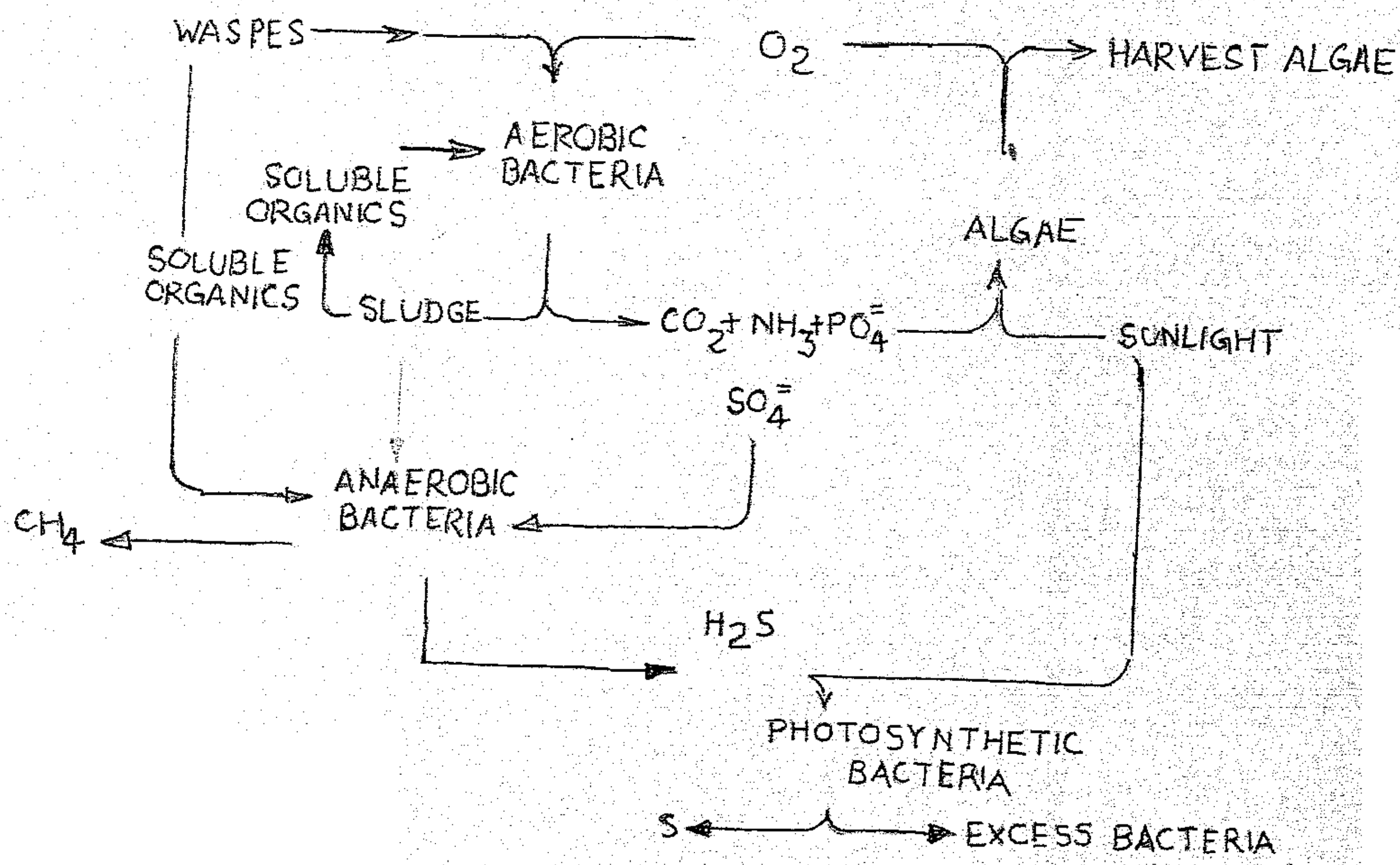
2.1 Algae in Oxidation Ponds

Because of being economical and simple in operation and maintenance, besides being effective as waste treatment unit, the oxidation ponds are employed commonly for sewage treatment. The function of sewage oxidation pond can be considered to be multiple. The pond can act as a reservoir to equalize the effect of peak loads on a sewage treatment plant, dilute concentrated sewage or waste, provide as well as act as an additional settling basin for treatment. The major difference between oxidation ponds and other types of sewage tanks or ponds lies in active photosynthesis taking place resulting in significant production of algae. Algae can thrive on nutrients in the sewage and, in the process of photosynthesis, produce oxygen. The oxygen produced by algae is available for maintaining aerobic bacterial decomposition of the sewage and prevention of odours(8).

The various symbiotic processes taking place in the oxidation pond are presented in figure 2.1(1). As the wastes come in the pond most of the suspended organic matter is observed to settle down with in a matter of a few hours to form sludge, this process is called auto-flocculation or bio-flocculation. The decomposition

FIG. 2.1

PROCESSES TAKING PLACE IN THE OXIDATION POND



of the remaining matter is started by the bacteria, and the decomposition results in producing Co_2, NH_3, phosphates and other compounds. In aerobic ponds the sludge undergoes decomposition aerobically and gives rise to the products mentioned. In facultative or anaerobic ponds, the sludge may, depending on climate and other factors, undergo partial decomposition, may increase in quantity without decomposition, or it may undergo partial or complete anaerobic decomposition.[1] The anaerobic decomposition involves two stages. One, called acid fermentation-utilizes oxygen from organic matter itself or from oxygen - rich anions like sulphates, nitrates and gives rise to H_2, CO_2, H_2S and other odourous gasses and to organic acids. The second stage involves, under favourable conditions, alkaline or methane fermentation as a result of which methane gas is formed together with some CO_2 and H_2. When organic matter is decomposed anaerobically the oxygen requirements decrease. Under favourable conditions of temperature, sunlight and nutrients, green algae usually grow in top layers of the pond. The algae use CO_2, ammonia and phosphates resulting from bacterial decomposition to synthesise algal cell material and release oxygen. Osweld(9) has given the following equation for the reaction.

$$NH_4^+ + 7.6\,CO_2 + 17.7\,H_2O \longrightarrow \underset{\text{algae}}{C_7H_{8.1}O_{2.5}N} + 7.6\,O_2 + 15.2\,H_2O + H^+ - 886\ \text{Cal.}$$

The oxygen released becomes available to the bacteria for the oxidation of dissolved organic matter. This cyclic process stabilizes the organic matter of the incoming waste. About 3.68 calories are fixed for each milligram of oxygen liberated and about 1.67 mg. of oxygen is liberated for each mg. of algae synthesised.

Disregarding phosphorous, sulphur and trace elements the oxidation of organic matter in sewage in high rate ponds has been found experimentally to follow the reaction:

$$\underset{\text{organic matter}}{C_{11}H_{29}O_7N} + 14O_2 + H^+ \longrightarrow 11\,CO_2 + 13\,H_2O + NH_4^+$$

2.1.2 Yield of Algae

Gotaas and Oswald(10) reported average yields of 30-35 tons of dry algae per acre per year from ponds at California, with yields of 60-75 tons per acre in July and August. Gotaas et al (11) also reported yields of algae of 600-1600 lbs. per million gallons of sewage. Renn(12) states that a population of 10,000 persons could produce 1400 lbs. of protein per day from algae grown in oxidation ponds. Meffert(13) obtained yields of the order of 7-10 gm/m^2 of surface per day during warm weather and 4g/m^2 per day during cool weather. In general the yield of 100-300 mg/l in oxidation pond effluents has been

recorded. Sengal and Siddiqi(14) recorded a value of above 400 mg/l at IIT-Kanpur Campus oxidation pond designed to treat the sewage of a population of 6000.

2.1.3 Species of Algae in Oxidation Ponds

The types of algae most active in oxidation ponds are chlorophyta (green) and cynophyta (blue-green). Typical algae species in oxidation ponds have been described by Arceiwala(15).

Blue green algae frequently flourish in ponds during summer months. Euglena has great adaptability to various pond conditions and are present during all seasons. Round(15) also states that species are controlled by season and place as different light intensity and temperature are conducive to the growth of different species. Singh et al studied the algae flora and physico-chemical characteristics of fifteen important towns of Uttar Pradesh. Thirty two species have been recorded. Cyanophycean species dominate over other groups of algae. Oscillatoria, Phormidium, Schizomeris and Navicula species were mostly encountered in the study. Arthospira, Euglena, Chlorella and Navicula were observed in the campus oxidation pond at IIT-Kanpur. Fitzgerald(8) concludes that the most numerous algae which grows on sewage is normally Chlorella, Scandesmus and Euglena.

2.1.4 Composition of Algae

The chemical compositions, neglecting sulphur and phosphorous, of Chlorella and Euglena are given as:

Chlorella $C_{7}H_{8.1}O_{2.5}N$

Euglena $C_{7.62}H_{8.08}O_{2.53}N$

Chlorella contains on an average 50-60% proteins, 20-30% fat and 10-20% carbohydrates along with amino acids and vitamins(14).

The growth and normal biochemistry of green plants, including algae, require the availability of from 15-20 elements. The table no.I indicates some of the elements required for green plants(17).

Table No. 1

Elements Required by Green Plants

Micronutrients (10^{-2}-10^{-4}M)	Micronutrients (10^{-5}M and less)
Carbon	Iron
Hydrogen	Mongnese
Oxygen	Copper
Nitrogen	Zinc
Phosphorous	Molybdenum
Sulphur	Vanadium
Potassium	Boron
Magnesium	Chlorine
Calcium*	Cobalt
Sodium**	Silicon

* Except for algae, where it is micronutrient
** For blue green algae

2.2 Harvesting of Algae

Harvesting of algae is difficult because algae are normally in dilute suspensions of about 400 mg/l, and of a small physical size which precludes simple sedimentation or floatation(18). The processing of algae undergoes the following three steps(19)

1. Initial concentration or removal
2. Dewatering
3. Final drying

The last step is needed only if the product is needed as food for animals, otherwise it can be dispensed with. After dewatering a slury of about 8-15% solids contents can be achieved(3).

A combination of small size (5-15μ) and low specific gravity results in a settling rate that is too slow to permit the use of settling as a routine procedure for harvesting algae. Some of the methods which are commonly used for harvesting algae are:

2.2.1 Centrifugation

Oswald and Golueke (18) report the removal of 84 percent at a throughput rate of 100 gpm to about 64 percent at 385 gpm at rotational velocities of 3000 and 3300 rpm for any algal culture having a concentration of 200 mg/l. It was also noted that the disc angle also affects the separation at throughput rates greater than

300 gpm. At a throughput rate of 385 gpm 52-64 percent removal was obtained with the disc angle 45^{o}, while separation increased to 74 percent with the disc angle of 55^{o}.

2.2.2 Chemical Flocculation

Coagulation can be induced by the addition of reagents such as aluminum sulphate, lime, organic or cationic flocculents. In coagulation the addition of the reagent is followed by a brief period of mixing to develop floc particles of sufficient size and density to permit rapid sedimentation and subsequent removal of flocculated material. Raising the pH of an algal suspension to 11.0 or higher results in the formation of a settleable gelatinous floc in which algae are trapped. Golueke and Oswald (19) report that very little precipitation occured at pH levels from 9.5 - 10.5, where as most of the algae were removed when the pH of the suspension was raised to 10.6. In addition, a large portion of the colloidal material was removed when the pH level reached 10.8. Little additional gain in clarity was obtained by raising the pH above 11.0. It was also noted that the use of $FeSO_4$ as an additive brought a distinct improvement in precipitation, the extent of which was in direct proportion to $FeSO_4$ dosage till a critical point of 40 mg/l reached. The required dose of $Ca(OH)_2$ also reduced correspondingly. 40 mg/l of $FeSO_4$ and 120 mg/l of $Ca(OH)_2$ gave a removal of 86% while a dose

of 200 mg/l of $Ca(OH)_2$ alone brought a separation of only 76%. Some of the results correlating the dose of $FeSO_4$ at various pH levels adjusted by $Ca(OH)_2$ for 85 - 87% removal are given in table no.2.

<u>Table No. 2</u>

pH Versus Dose of $FeSO_4$

pH	10.5	10.9	10.10	11.0	11.1
$FeSO_4$ mg/l	120	100	60-80	40	0

No precipitation was observed at pH levels below 10.5 regardless of $FeSO_4$ dose.

Aluminium Sulphate is also commonly used as a flocculent. Best removal with this is obtained at a pH of 6.5. The pH range of 6.0 - 6.8 gives quite good removal, while beyond pH 7.0 the removal becomes increasingly poor. A mixing time of 3 minutes at a blade tip velocity of 12 in/Sec with 15 minutes of settling time with 75 mg/l of $Al_2(SO_4)_3$ gave 99% removal. The clarity and sparkle of the supernatant at dosage of 105 - 120 mg/l closely approximated with that of tap water (19).

Sinha (20) reported a removal of 91.2% by alum dose of 400 mg/l at pH 7.0, and without pH adjustment of the oxidation pond effluent the dose for the same removal was 900 mg/l at pH 8.7.

Gulueke et al (19) when algal suspension was passed through two electrodes, placed 1/8 to 1/2" (0.32 - 1.27 cm) apart. Test rates ranged from 0.05 - 1.2 gpm/cft (6.7 - 160 l/min/cum) of electrolyte cell volume. Current was varied from 0 - 900 milli amperes.

Electrodes of carbon, copper and aluminum were used either as pairs of one material only or as pairs comprised of different materials. Excellent separation was achieved when aluminum or copper electrodes were used, because an excellent floc was formed by the release of copper and/or aluminum and the subsequent formation of copper and/or aluminum hydroxide. Very little if any separation took place when two carbon electrodes were used.

2.2.6 Other methods

Besides all these methods mentioned for harvesting of algae, filteration through sand beds, ion exchange and ultrasonic vibrations can also be used.

2.3 Fundamentals of Anaerobic Digestion of Organic Sludges

Direct disposal of organic sludges and other concentrated wastes either in streams or on land causes various problems. It becomes imperative to subject them to some sort of treatment and bring them to a level where their disposal becomes easy. One of the methods which is effective and is in use, is anaerobic stabilization.

2.2.3 Foam Floatation

Levin (21) reports that in the floatation method the cell concentration of the harvest is a function of pH, aeration rate, aerator porosity, feed concentration and the height of foam in the process coloumn. Apparantly through a change in the surface characteristics brought about by exposure to low pH, algae are trapped and collected in the foam. Ramchandran (22) obtained a removal of 85% in 10 minutes using 20 mg/l of a cationic surfactant (hexadecyl pyridinium chloride) and 100 mg/l of alum with 1.5 VVM air flow rate. The Scum obtained had 2% solids content. The effect of pH on removal was quite considerable. The best removal was obtained at pH 3.0 and 11.0.

2.2.4 Autoflocculation

A natural separation process was observed (19) which took place under certain conditions. The phenomenon consisted of a naturally causing precipitation and settling of algae. The required conditions for this are reported as.

a. actively photosynthesising shallow culture

b. relatively warm day

c. sun light

In this the pH of the media increases above 9.5.

2.2.5 Passage through Charged Field

Excellent separation of algae was obtained by

Anaerobic treatment is a three step process:

a. Hydrolysis of Complex Material:

In this complex organic matter is converted to less complex soluble organic compounds by enzymatic hydrolysis with the help of extracellular enzymes.

b. Acid Production:

Here the hydrolysis products are fermented to simple organic compounds, predominately volatile acids (acetic acid, propionic acid, formic acid etc.), by a group of facultative and anaerobic bacteria collectively called "acid - formers".

c. Methane Fermentation:

This step ferments the simple organic compounds to methane and carbon dioxide. This is carried out by a group of substrate specific, strictly anaerobic bacteria called "methane-formers". Both acid production and methane fermentation are intracellular processes (23,24).

Thus, organic waste materails are converted effectively to bacterial protoplasm and gaseous end products, mainly methane and carbon dioxide. This is represented schematically in fig 2.2The slowest and rate limiting step in this sequence is the third step, the methane fermentation.

Compared to aerobic process of stabilization of wastes the anaerobic treatment has following advantages (25).

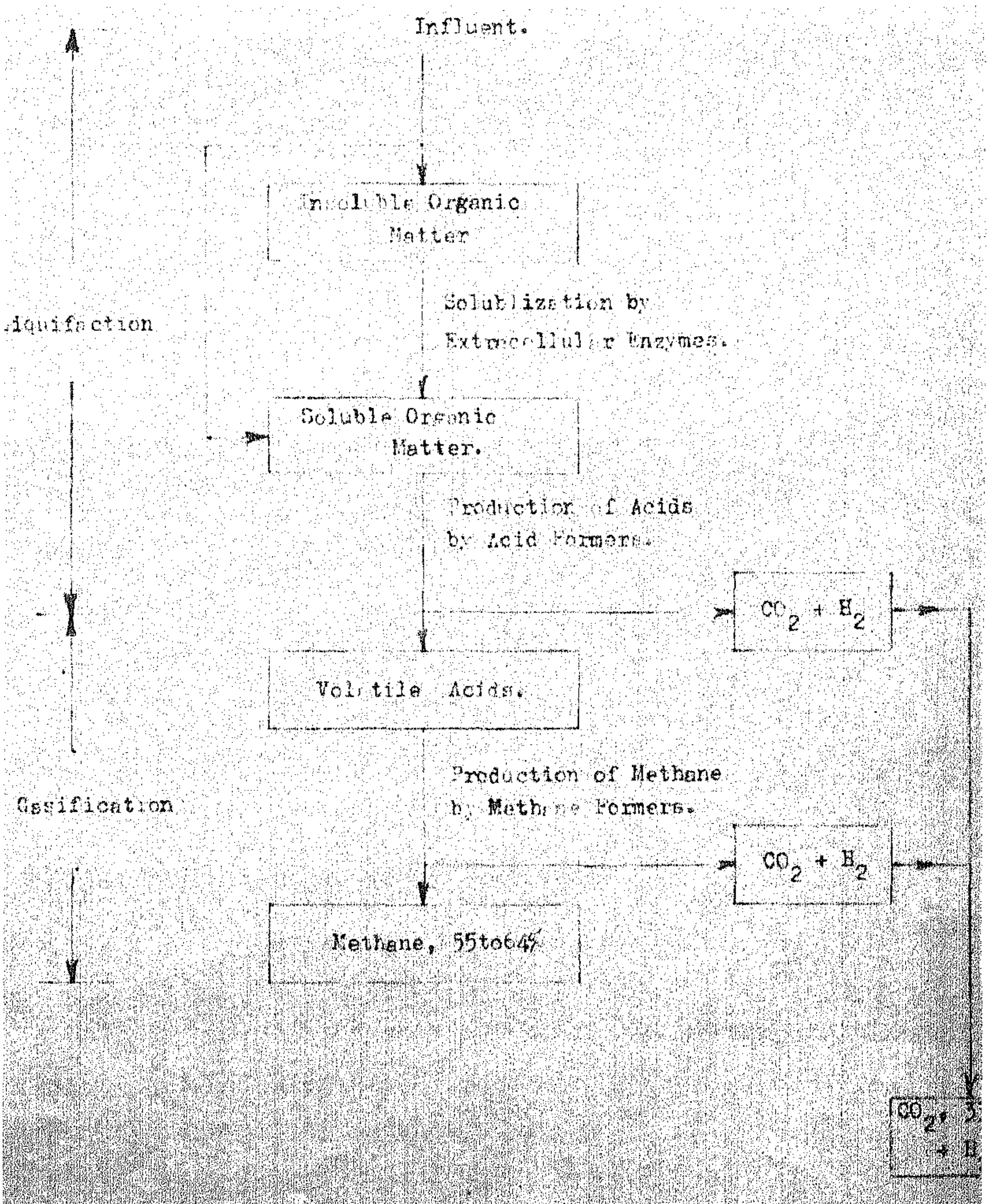


Fig.2.2: Schematic Representation of Reactions in Anaerobic Digestion.

1. High degree of waste stabilization is possible
2. Low production of waste biological sludge
3. Low nutrient requirement
4. No oxygen requirement
5. Methane is a useful end product

Besides these advantages there are some disadvantages associated with anaerobic process. Some of them can be listed as

1. The methane - fermentation stage is a temperature sensitive stage hence requires maintenance of relatively high temperatures (85 - 95°F).

2. Because of slow rate of growth of methane producing bacteria, relatively larger detention times are needed.

But the advantages outweigh the disadvantages when concentrated wastes, with BOD values greater than 10,000 mg/l are subjected to this treatment (25).

The optimum environmental conditions for more efficient and rapid treatment are (26)

1. <u>Optimum Temperatures</u>

a. Mesophilic range 85° - 110°F

b. Thermophilic range 120° - 130°F

The two optimum temperature levels for anaerobic treatment were reported by Fair and Moore (27). The stabilization at higher temperatures, thermophilic ranges,

proceeds faster as compared to mesophilic ranges. But the extra cost involvements for maintaining higher temperatures may offset the advantages obtained. However Fischer and Green (28) report that bacteria can function with equal ease from 35° - $60^{\circ}C$ without any derogatory effect upon the degradation and gas production. The only important point is that sufficient time has to be provided for the population build up of bacteria for the smooth running of the treatment unit.

For the digestion process to be most effective, the temperature chosen must be uniform and maintained with a narrow range of a few degrees of temperature above or below the established value (29).

2. Anaerobic Conditions

Methane - formers are strictly anaerobic. As the culture becomes purified exposure to oxygen even for a short time has an inimical effect on the organisms. In mixed cultures with an abundant supply of food, such as in sludge, the activities of other organisms protect the methane organisms by removing any oxygen that may be present or that may find access. The highly reducing conditions required by methane organisms are produced by the activities of a variety of organisms. Since methane organisms in pure culture can neither dispose of oxygen nor create highly reducing conditions, oxygen can be considered as toxic to them (26,30).

3. Sufficient Biological Nutrients

The anaerobic process is dependent upon bacteria, which require certain elements for their growth. The basic requirements of elements for bacterial growth include carbon, nitrogen, oxygen, phosphorous, potassium, sodium, magnessium, calcium, sulphur and iron, in decreasing order. The bacteria must derive all these basic elements for protoplasm from the liquid environment. If the environment is deficient in one or two elements, the bacteria will develop only in proportion to the chemical deficiency (26,31).

4. Optimum pH

The importance of pH on digestion has been demonstrated on numerous occasions. Most authorities accept that a pH of about 7.0 gives optimum conditions and indicates a balanced chemical activity in the unit. The methane formers are highly sensative to pH changes. Henkerckin (32) has shown that number of methane formers decreases at pH values below 7.0. He further reported a suitable pH range of 7.2 - 7.8. Although pH changes generally follow variations in volatile acid concentration, pH on its own does not provide a reliable check on gas production (24). There are two different opinions regarding the pH adjustement in the digesters. One group recommends the use of lime to nutralize volatile acids in order to promote a favourable pH (33). The other group forbids its use completely (34).

5. Absence of Toxic Materials

There can be many materials both, organic and inorganic, which may be toxic or inhibitory to the organisms involved in anaerobic waste treatment process. The term toxic is relative and concentration at which a material becomes toxic or inhibitory may vary from a fraction of milligram to several thousand milligrams (11) McCarty and McKinney (35) have shown that a single cation is more toxic if present alone in the digester than a combination of cations. Certain cations have been studied, they are in order of toxicity, based on equilent concentration, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, NH_4^{+}.

McCarty (36) reported that at pH 7.4 - 7.6 the ammonia gas concentration can become inhibitory. When ammonia - nitrogen concentration exceeds 3000 mg/l then ammonium ion becomes quite toxic regardless of pH. The heavy metals like copper, zinc and nickel are quite toxic even at low concentrations. Sulphides concentrations above 200 mg/l are quite toxic. Organic compounds like alcohals and fatty acids are also toxic.

Table No. 3 gives inhibitory concentration of some of the ions.

Table no.3

ion	moderately inhibitory mg/l	strongly inhibitory mg/l
Na^{+}	3500-5500	8000
K^{+}	2500-4500	12000
Ca^{++}	2500-4500	8000
Mg^{++}	1000-1500	3000
$S^{=}$	150	>200

2.3.1 Organic loading of anaerobic digestor

The anaerobic digesters in literature have been classified as standard - rate and high-rate digestion (38). In standard rate digestion little provision is made for mixing. As a result, influent organics are concentrated locally at points in the tanks and contact with microorganism population is limited. While in high-rate digesters the contents are maintained in a mixed state by means of vigrous agitation. Retention time for high-rate process is of the order of 10-15 days. The capacity requirements are reduced by prethickening the influent sludge. Conventional anaerobic digestion tanks are usually loaded at a rate of 0.03 - 0.04 lbs. volatile solids / cu ft/ day with a detention period of about 30 days (39) while loading in high rate digestion systems may range from 0.1 - 0.2 lbs. volatile solids per ft^3 per day with dention period of 10-15 days (39).

Caldwell and Sawyer (40) advocated a minimum detention of 20 days for high rate digestion. Ruddolf and Miles (41) recommended a detention period of 20 days for low temperature (27.5 - 29.5°C) and 15 days for higher temperature (49° - 52°C).

However according to Sawyer (42), there is no line of demarcation between conventional and high rate digester loadings. Digester behavior and character of the end products appear to be more related to detention period than to organic loading.

2.3.2 Gas Production

Dunston and Hinden (43) have reported a gas production of 9.33 ft^3/lb. volatile matter added per day at a loading of 0.05 lbs/ft^3/day volatile solids with a hydraulic detention period of 33 days. At the same detention period, organic loading of 0.135 lbs./ft^3/day volatile solids, a gas production of 5.23 ft^3/lb VM added was reported. Sawyer and Roy (44) using pilot plant reported a gas production of about 9 cft/lb. VM added at a detention period of 10 days.

Seth et al (45) obtained 38 percent reduction in volatile solids content at a detention time of 11 days for the sewage sludge obtained from a primary sedimentation tank. The gas yield was found to be 8 cft per pound of volatile solids destroyed per day. It was also reported that this value is about 50% of the values reported in U.S.A. The gas composition was found out to be 65 - 70% CH_4 and about 30 - 35% CO_2.

Harishchandra and Saxena (46) obtained 86.24 percent reduction of BOD and volatile solids at a max. loading of 0.1823 lb. BOD per cft/day and 0.1927 lb. VS/cft/day respectively at a detention period of 15 days. The gas yield varied from 20.81 to 6.0 cu ft/day/lb of V.S destroyed.

Sen and Bhaskaran (47) report a gas yield of 14 cft/day per lb. BOD applied in the case of distillery wastes at a loading of 0.186 lbs/cft/day with a detention time of 10 days. While Chakrabrity and Trivedi (48) recorded

the yield of 11 cft of gas/lb volatile solids added. In the case of cheese wastes 14 - 16 cft of gas was produced per lb. of VS destroyed. Sewage sludge produced about 16 - 18 cft of gas per lb. of VS destroyed (46).

Digester gas generally contains 72% methane and is saturated with water vapour. The net fuel value of methane is 963 Btu per cu ft under standard conditions. (The net fuel value is the heat liberated in combustion minus the heat of condensation of water (6).

2.3.3 Treatment of Wastes by Anaerobic Digestion

Under some circumstances anaerobic digestion is the most economical method of reducing the BOD of wastes to an extent aerobic treatment will then produce a liquid fit for discharge into water course. It has so far been applied to meat packing, milk, yeast, distillery, wool, scouring, starch, rice, candy, pea blancher, straw board, citrous, tannery and other wastes.

Recent studies on antibiotic wastes by Heukelekian(49) indicated that anaerobic digestion, with slight agitation and pH control is feasible. This method was found to reduce the BOD approximately by 80%. Liquids then could be treated on spent filters to yield final effluents having 35 - 40 mg/1 of BOD. Table 4 gives the nature of treatment obtained in some of the industrial wastes.

Table No. 4

Treatment Performance in Anaerobic Digestion

Waste	Hydraulic detention time	Digestion temp.	Vol.Solids added	BOD reduction	Reference
Pea Blencher	3.5	131°F	700 lbs/1000 cft/day	-	50
Rye fermentation	2	130°F	930 "	-	51
Corn fermentation	4.0	130°F	330 "	-	
Butanol	10.0	-	190 "	-	
Meat packing and Slaughter house	-	-	1200-2000 mg/l BOD	95%	52
Molasses and distillary waste	10	37°C	3.01 kg/cum/day	90%	53
Fiber board waste	-	-	0.64 kg/cum/day	94%	54
Dairy waste	6	-	0.54 kg/cum/day	90-99.5%	
Spent vegitable tan liquor	32	37°C	0.54 kg/cum/day	96%	

2.4 Anaerobic Digestion of Algae

Algae being a living thing its protoplasm contains all the essential macro and micro nutrients required for any biological growth. The chemical formula for organic matter in the waste as well as for the algae as given below are also quite similar:

Algae - $C_7 H_{8.1} O_{2.5} N$

Organic matter - $C_{11} H_{29} O_7 N$

Seeing from all this it seems that algae will be easily digestible as any other organic matter.

But not much reporting has been done in literature regarding the controlled digestion of algae. Though it has been reported on several occasions that on dying algae settles with other settleable organic matter to the bottom of oxidation ponds and in facultative and anaerobic ponds it starts degrading anaerobically with other organic matter. This decomposition gives rise to gases like H_2, CO_2 and H_2S in the first stage where this organic matter utilizes oxygen from organic matter itself or from oxygen rich anions like sulphates and nitrates. The second stage involves methane fermentation as a result of which methane gas is formed together with some CO_2 and H_2.

This observation confirms that algae is digestible anaerobically and it can yield economical products if the digestion is carried out under controlled conditions like optimum loading, detention time and temperature for maximum gas yield. This study was carried out with this objective

in mind, also the emphasis was laid on finding out suitable methods for harvesting algae from the oxidation pond effluent and seeing the effect on digestibility of algae because of these different modes of separation used.

Chapter 3

Materials and Methods

3.1 Sewage Oxidation Pond

The IIT Kanpur campus oxidation pond is rectangular in shape, 400X200 feet and 4.5 feet deep. The BOD loading is 640 kg/hectare-day or 575 lbs/acre-day and the theoretical detention period comes to about 3 days. It has sloping sides laden with open jointed bricks. The bottom comprises of natural earth, to promote seepage. The sewage is pumped intermittently, when sufficient waste water gets accumulated, through a pipe which extends into the pond by about 20 feet. The out-let is on the opposite side. The effluent was the source of algae for digestion.

3.2 Harvesting of Algae

For harvesting of algae three methods were tried:

1. Autoflocculation or bioflocculation
2. Chemical coagulation
3. Foam floatation

3.2.1 Autoflocculation or Bioflocculation

The harvesting unit consisted of two oil drums connected near the bottom. The drums were filled manually and were covered for four days. The sludge was recovered by draining of the liquid through an outlet near the bottom in

one of the tanks. Then the sludge was thickened and the thickening was done by filtering out the extra w-ter through cloth. The thickened sludge contained total solids about 20,000 mg/litre.

3.2.2 Chemical Coagulation

For chemical coagulation potash alum was used as the main coagulent while peptone and $KMnO_4$ were tried as coagulent aids. The flocculation time of 15 minutes at 60 rpm and a sedimentation time of 30 minutes was used.

The pH adjustment of algal suspension was done by 0.5N HCl solution.

3.2.3 Foam Floatation

For foam floatation the surfactant used was Hexa decyl Trimethyl Ammonium Bromide ($CH_3\ (CH_2)_{15}\ N^+(CH_3)_3\ Br^-$) was used. Alum, $KAl(SO_4)_2.12H_2O$ was also tried as flocculent aid. The floatation column used was of 1.25 metre length and 7 cm. diameter with a sparger fixed to the bottom. The outlet for the foam was in the middle of the column as shown in the figure 3.1.

All experiments were carried out with a sample volume of 1 litre. The floatation time of 2.5 minutes was used.in each case.

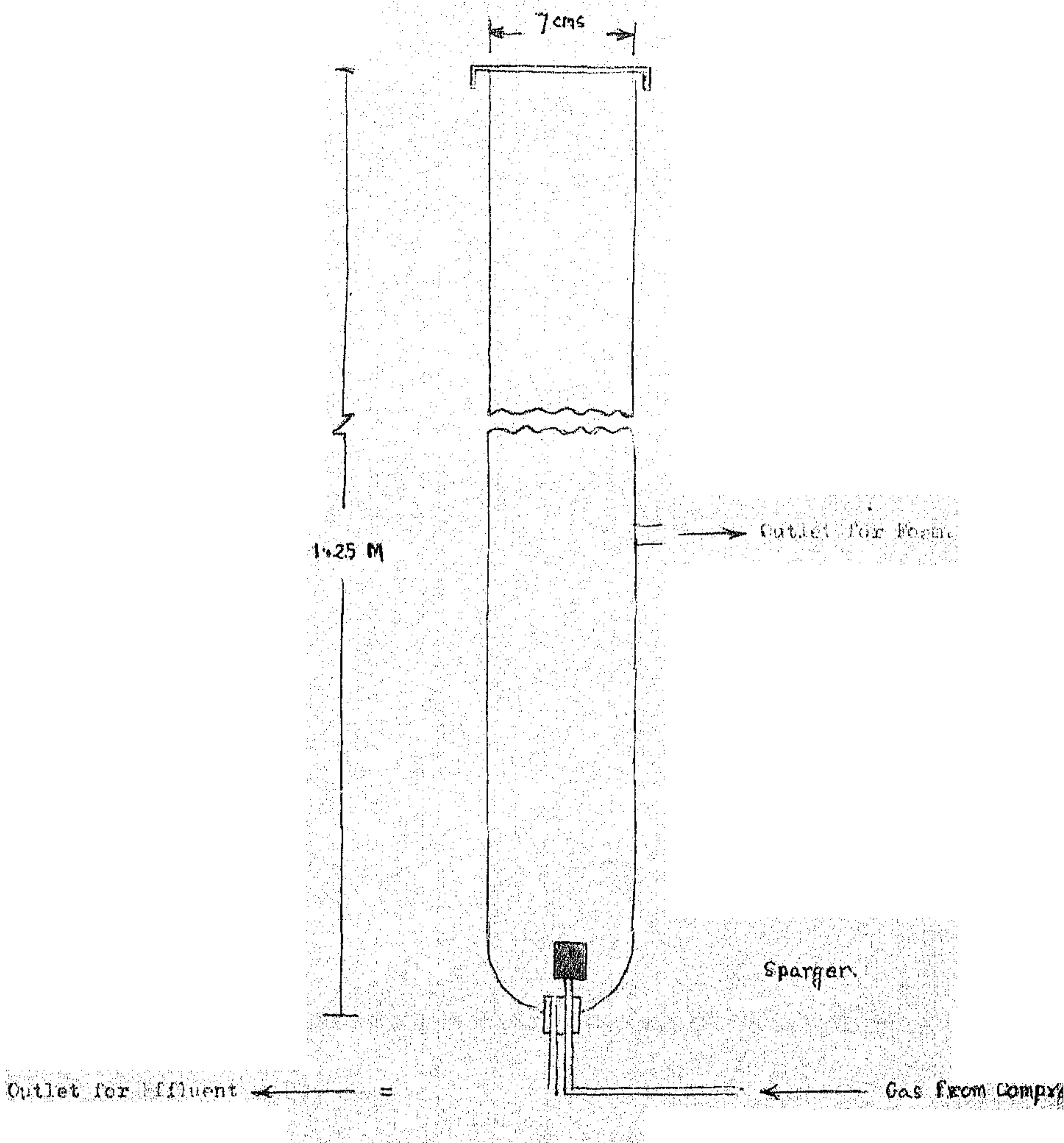


Fig. 3.1; FLOATATION COLUMN.

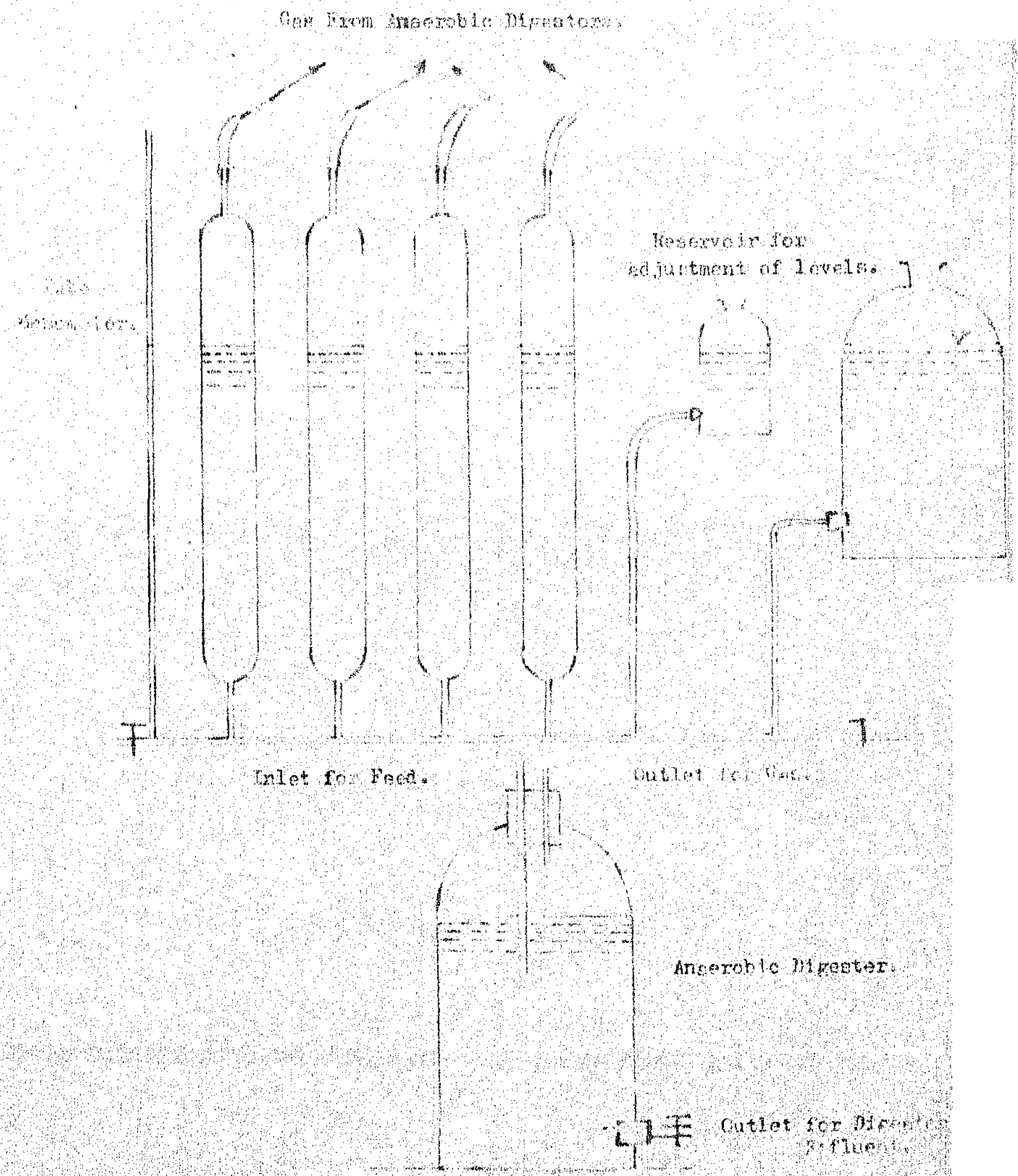


Fig.3.2: Experimental Set-up.

3.3 Digestion

Digestion was started at two temperatures, 35°C in mesophilic range and 55°C in thermophilic range. Four digesters having 1.5 litre contents were used, two for glucose, which acted as controls while the other two for algae at the two temperatures mentioned earlier. The digestion time was chosen as 30 days.

The digesters were started with cowdung slurry acclimatized to algae by feeding glucose and algae together with the nutrients daily till the gas production stabilized. Then feeding of glucose was stopped and only algae with nutrients was fed till the digesters picked up. For meeting the nutrient requirements in glucose digesters one ml of solution I and solution II was added with the feed. Then the temperature of two of the digesters, one for glucose and one for algae was raised in steps of 2 degrees centigrade daily from 35°C to 55°C . The digestion of algae was also tried without the addition of nutrients so as to see whether all the nutrient requirements for microbial growth can be met by its constituents or not.

Feeding was done daily once. Hundred ml. of the digester liquid was withdrawn after mixing. After 30 minutes of sedimentation 50 ml. of the supernatant was wasted or kept for analysis while the sludge was recirculated with 50 ml. of fresh feed with nutrients.

The gas was collected, at $35^{\circ}C$ and at atmospheric pressure, in graduated cylinders containing saturated solution of NaCl and five percent H_2SO_4 with some Methyl red. This solution was used so as to have actual amount of gas produced to be recorded without losing any part of it in dissolved form. The gas was wasted unless used for analysis.

The experimental set up is shown in figure 3.2.

Methods of Analysis

Concentration of algae was determined by spectrophotometer at 435 mμ wave length. The standard curve was obtained by taking the oxidation pond effluent absorbance at 435 mμ and then finding out its total solids content. From this total dissolved solids of the liquid without algae were subtracted. For separation of algae the sample was centrifuged at 5,000 rpm for 10 minutes.

pH of the digester liquid was obtained immediately after its withdrawal from the digesters.

Percentage volatile solids content was determined according to the method recommended in Standard Methods (55).

Mixed liquor suspended solids (MLSS) were determined by allowing the suspended solids in the digester effluent to settle in Imhoff cylinders. The sedimentation time used was 30 minutes.

For gas analysis Orsat apparatus was used.

Table 5

Stock Solutions of Inorganic Nutrients added to Digester.	
Solution 1	Solution 2
45.6 mg $(NH_4)_2HPO_4$	28 gm NH_4Cl
Diluted to one liter	4 gm Kcl
with distilled H_2O	10 gm $MgCl_2 6H_2O$
	5 gm $FeCl_3$
	0.1 gm $(NH_4)_6 Mo\,O_{24} + 4H_2O$
	0.01 gm $ZnCl_2$
	0.57 gm $CoCl_2+6H_2O$
	0.25 gm $MnSO_4 . H_2O$
	1.0 gm $CaCl_2 . 2H_2O$
	1.12 gm $AlCl_3 . 6H_2O$
	diluted to 1 liter with
	distilled H_2O

Chapter 4

Results and Discussions

4.1 Campus Oxidation Pond, The Source of Algae

The campus oxidation pond which was the source of algae for this study is designed to treat the sewage of the campus. The total contributing population is about 6000. The characteristics of the sewage and the extent of treatment affected in the pond ie. the influent and effluent characteristics are shown in table no. 6.

The BOD loading of the pond comes to 640 kg/hectare-day (575 lbs/acre-day) and the theoretical detention period comes to about 3 days. As shown in table no. 6. the normal algae concentration in effluent is 412 mg/l and hence the total dry weight of algae daily going out in the effluent is about 1000 kg (14).

The continuous and effective working of the oxidation pond and a more or less uniform concentration of algae in the effluent throughout the year clearly indicates that the light intensity available at Kanpur even on cloudy days as well as during winter is more than the saturation intensity. Hence light intensity is not limiting in Kanpur for the working of oxidation ponds, and most of the Indian cities have a light intensity equal to or more than Kanpur. Hence oxidation pond as a waste treatment unit seems to be quite effective and cheap under Indian conditions throughout the year and the effluent from such ponds will contain algae in concentration

Table no. 6

Characteristics of influent (Sewage) and effluent from oxidation pond

S.No.	Parameter	Conc.of influent	Characteristics of effluent
1	Temp. °C	25-26	29-31
2	Total solids mg/l	1023	860
3	Total suspended solids mg/l	467	-
4	Volatile suspended solids mg/l	210	-
5	Volatile dissolved solids mg/l	240	-
6	Ammonia Nitrogen mg/l	6.5	2.83
7	Organic nitrogen mg/l	8.0	5.2
8	Total phosphates mg/l	5.2	2.8
9	Chlorides, mg/l	65.8	-
10	pH	7.9	8.8
11	COD mg/l	279	-
12	BOD, 5 day, 20°C, mg/l	136	25
13	BOD, ultimate, mg/l	210	135
14	Flow 10^6 l/d	2.8	2.7
15	Algae conc. mg/l	-	412
16	DO mg/l	-	8.9

around 400-600 mg/l by dry weight and can serve as a copious source of algae for different modes of utilization including that to produce fuel gas by anaerobic digestion.

4.2 Harvesting of Algae

In harvesting of algae from the pond effluent main objective was to find out a method which is economical and effective, also which yields algae which can be digested in anaerobic digesters. The methods tried were:

1. Autoflocculation or Bioflocculation.
2. Chemical coagulation.
3. Foam floatation.

4.2.1 Autoflocculation or Bioflocculation

The method tried was slightly different than the autoflocculation phenomenon reported by Oswald (18). According to him natural separation of algae termed autoflocculation takes place in actively photosynthesising shallow culture on a relatively warm day in bright sunlight. In this study it was observed that if the effluent from oxidation pond is detained in tanks of about 3 feet depth in the absence of light then a natural separation is observed in about 4 days. Most of the algae goes to the bottom while some of it is carried to the surface. This natural sedimentation may be because of the algae getting killed in the absence of sunlight and nutrients. The floating of algae to the top may be because of the gases, being released in the anaerobic activity in the pond, which

carry it along with them to the surface.

A removal of about 80% was obtained in 4 days detention time. The slurry obtained had total solids contents of about 6000 mg/l. As tabulated in table no. 7 with the solids having an average 88.6% volatile contents. The rest of the solid matter, about 11% is in the form of fixed inorganic matter which is not available for digestion.

4.2.2 Chemical Coagulation

Alum ($KAl(SO_4)_2 \cdot 12\,H_2O$) and Sodium aluminate ($NaAlO_4$) were used as chemical coagulents. Coagulent aids like peptone and potassium permangnate were also tried with alum.

86% removal was obtained with 2000 mg/l of alum dose at a pH of 8.92 i.e. without any pH adjustment of the oxidation pond effluent. The algal suspension had a concentration of 520 mg/l. With the adjustment of pH 7.0 the dose requirements for alum reduced to 1000 mg/l for the same percentage of removal. These results are plotted in Fig. 4.1.

12 hours of sedimentation of this algal sludge yields a slurry of about 6000 mg/l total solids as given in table no. 7. This has a volatile solids content of about 44%. This value of volatile solids contents is half as compared to the slurry obtained by bioflocculation. The reason for this low VS content is the large amount of inorganic chemical which comes with the slurry during harvesting. These figures

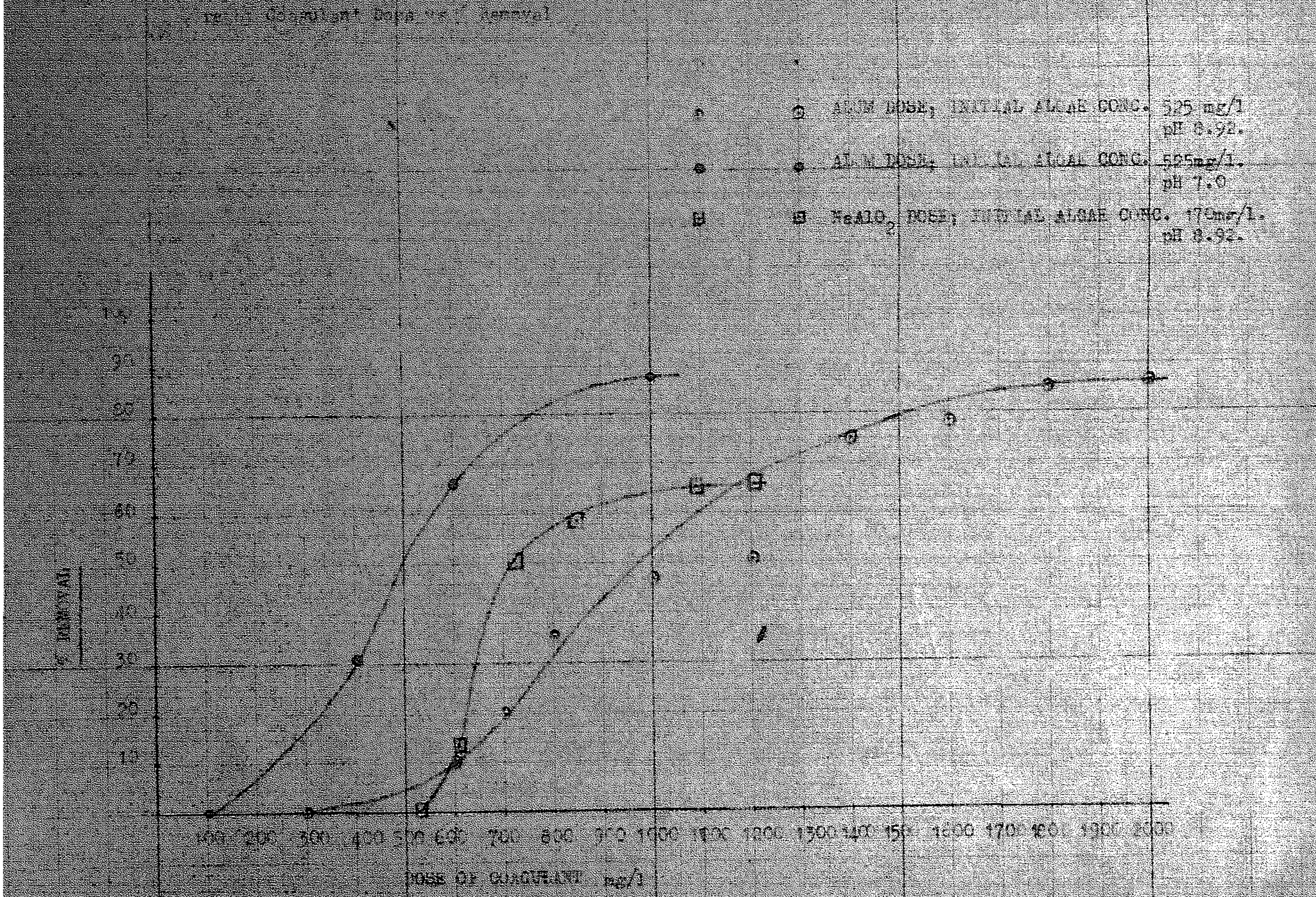
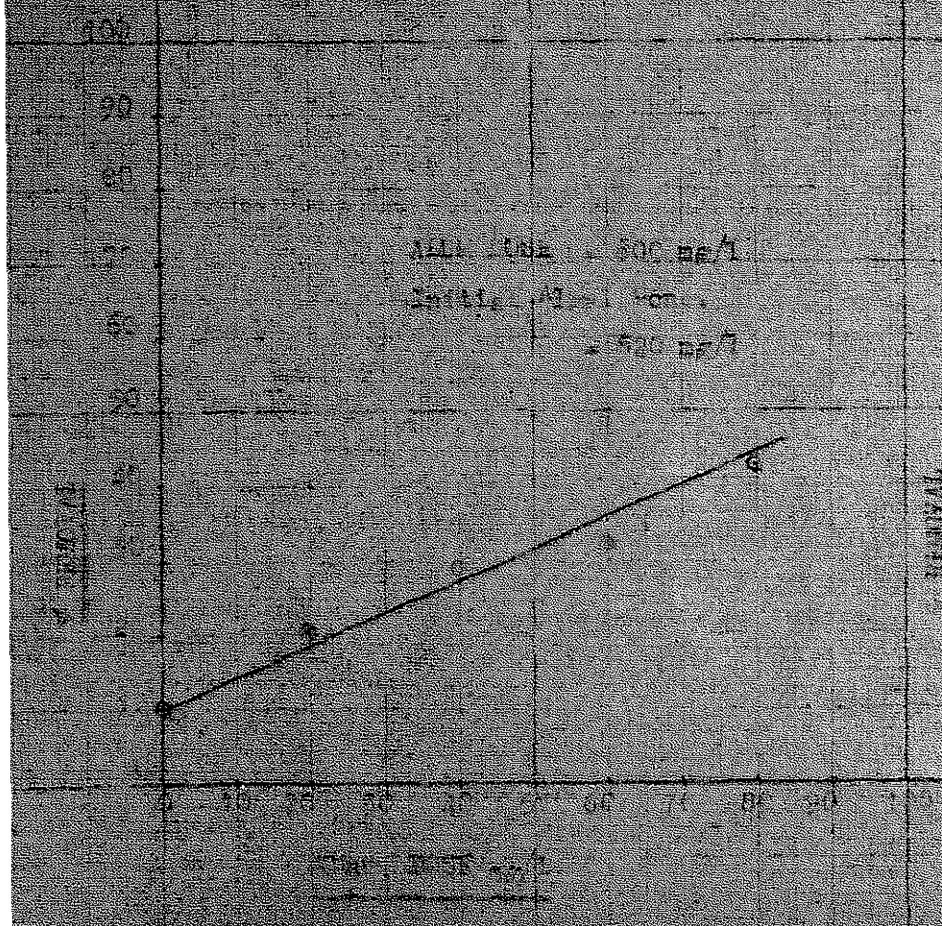
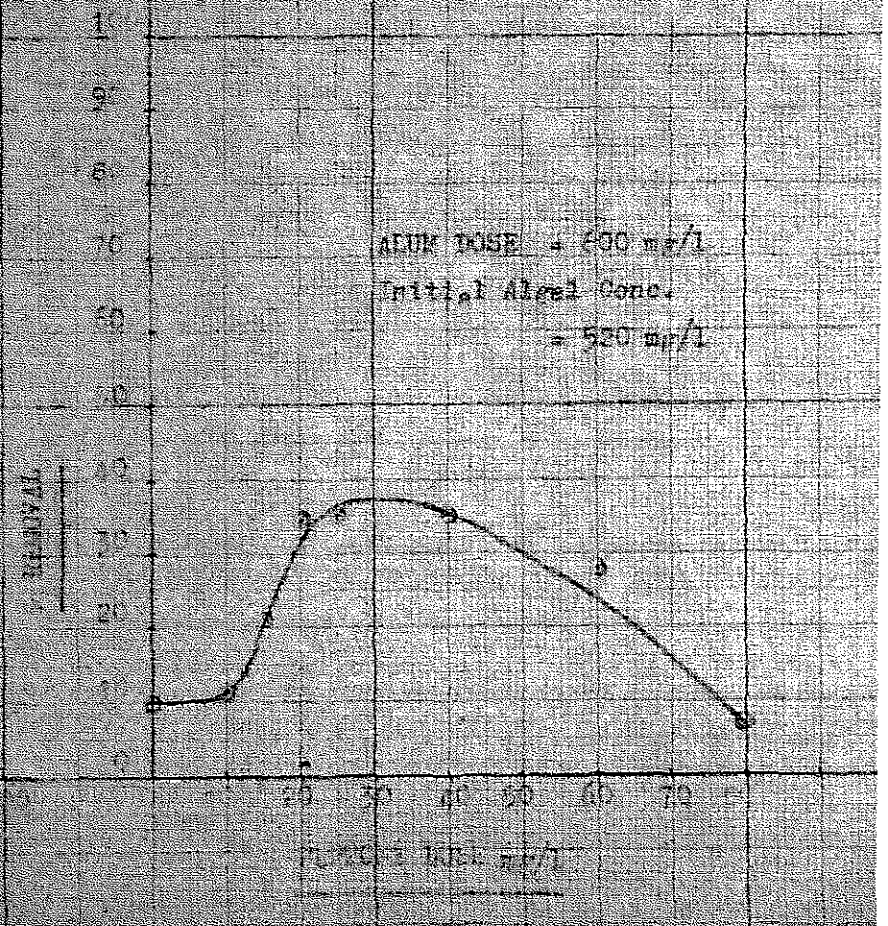

ALUM DOSE; INITIAL ALGAE CONC. 525 mg/1 pH 8.92.
ALUM DOSE; INITIAL ALGAE CONC. 525mg/1. pH 7.0
$NaAlO_2$ DOSE; INITIAL ALGAE CONC. 170mg/1. pH 8.92.
% REMOVAL
DOSE OF COAGULANT mg/1

Figure. 4.1.

Graph: $KMnO_4$ Dose as Coagulant Aid with Alum vs Removal of Algae.



Graph: Peptone Dose as Coagulant Aid with Alum vs % Removal of Algae.



indicate that alum coagulated algae has about 56% of its total weight as fixed inorganic matter and of this as much as about 44% is really a part of the alum which was added as a coagulating agent. Effectively the quantity of digestible algal solids in alum coagulated sludge is only about half of that in auto-flocculated sludge.

With peptone as a coagulent aid to alum there is an improvement in removal obtained. A dose of 25 mg/l peptone and 600 mg/l of alum gives a removal of about 38% while alum alone at 600 mg/l gives only 10% removal as shown in Fig. 4.2. Peptone was used as an aid because it will also provide essential nutrients to the bacteria for carrying out digestion. But because of low removal this method is not very effective.

Fig. 4.3 shows that percentage removal of algae goes on increasing with $KMnO_4$ in direct proportion to its concentration when used as an aid to alum. It increases the removal from 10% to about 47% at 8 mg/l concentration with alum concentration of 600 mg/l. Large doses of $KMnO_4$ cannot be used as it is a toxic material to biological growth.

4.2.3 Foam Floatation

Foam floatation is gaining importance with the increasing use of surface active agents for separation of algae. The surfactant used was Hexa decyl Trimethyl Ammonium Bromide ($CH_3(CH_2)_{15}N^+(CH_3)_3Br^-$). This surfactant gives quite good removal even at low concentrations. A removal of 79.2% was

Table no.7

% volatile content of algal sludge harvested by different methods

Sample	Method of Harvesting	Total solids mg/l	Volatile solids mg/l	% volatile solids
1	Autoflocculation*	18264	16276	88.4
2	"	18438	16218	88.64
3	"	20700	18665	90.15
4	"	19850	17600	88.68
5	"	18760	16810	89.70
6	Alum coagulation	5947	2614	43.43
7	"	5873	2593	44.20
8	"	6127	2700	44.70
9	Foam Floatation	3980	3505	88.0

* Values reported are after thickening of sludge.

Each sample is average of 2 or more readings.

obtained with a dose of 25 mg/l with 2.5 minutes of time of floatation for an algal suspension of 460 mg/l. Further increase in dose did not bring any improvement in removal. The use of alum as an aid to floatation did not bring any significant increase in removal as is shown in figure 4.4.

This surfactant has a better action than Hexadecyl Pyridinium Chloride ($C_{21}H_{38}$ Ncl) which gave maximum removal of about 53% with 20 mg/l of the dose for a floatation time of 10 minutes and for an algal suspension of 90 mg/l. But in this case alum dose of 100 mg/l increased the removal from 53% to 69% (22).

The algal sludge obtained from foam floatation has a total solids content of about 4000 mg/l with about 88% of it volatile.

4.3 Anaerobic Digestion of Algae

4.3.1 Digestibility of Algae

The results tabulated in tables 8,9,D show that algae is easily digestible anaerobically at 35°C. But the percent digestibility of algae is less than that of glucose at both the temperatures (35°C and 55°C). This is clear from figure no. 6 also. Comparison of values from tables 8 and 9 show that algae and glucose degradation percentage is 51 and 78 at 35°C while it increases to 57 and 87 at 55°C at a loading of about 0.03 lbs/cft-day. The gas produced per pound

Graph: Surfactant Dose vs % Removal of Algae.

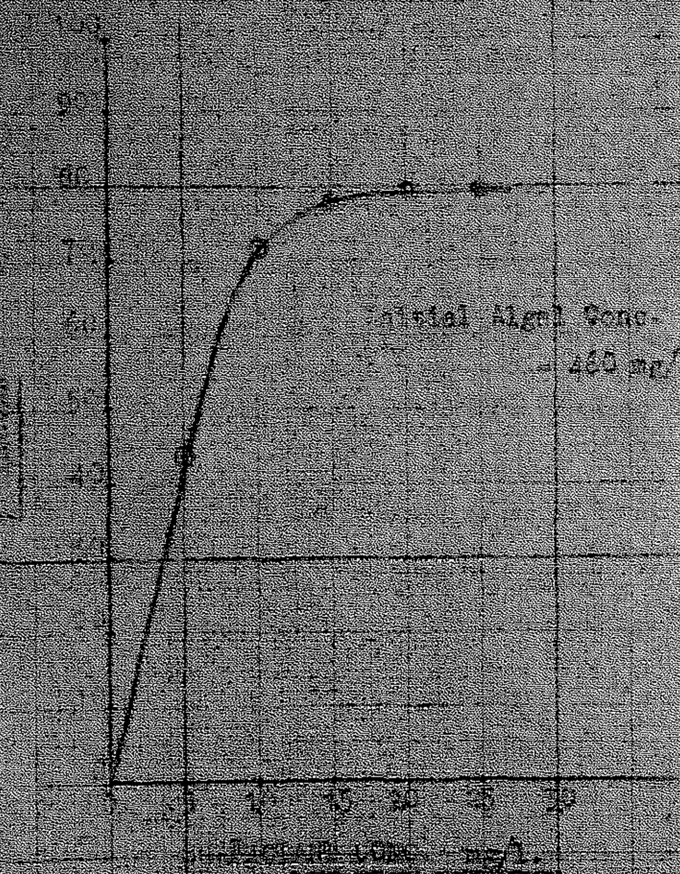


Figure. 4.[illegible]

Graph: Alum Dose as Surfactant Aid to Surfactant vs Removal of Algae.

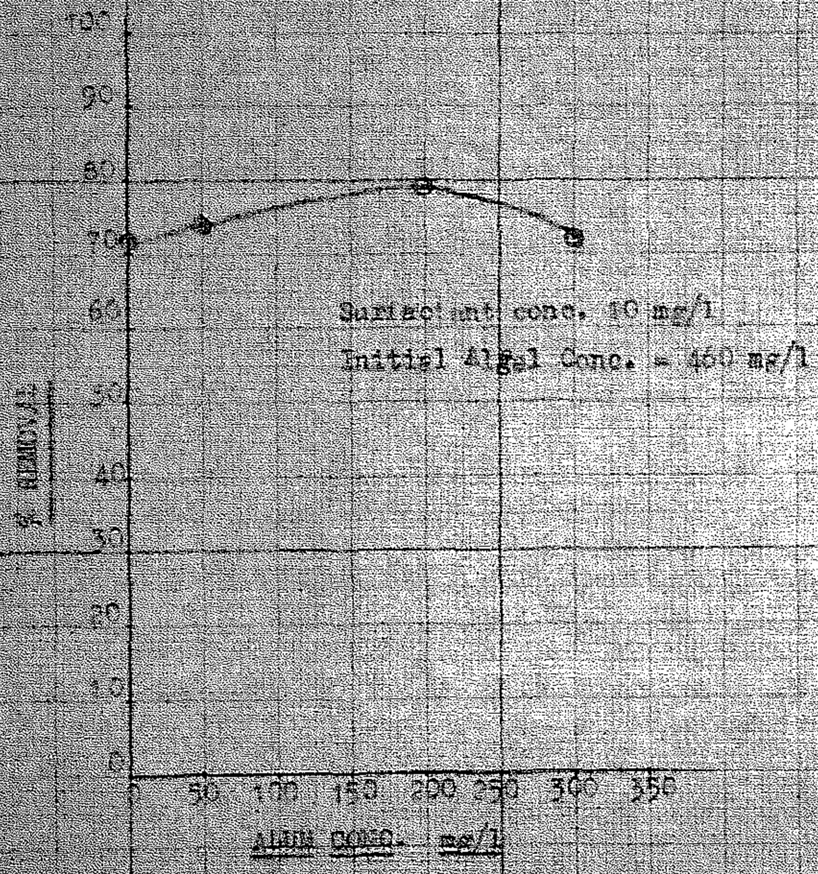


Figure. 4.[illegible]

of volatile matter destroyed is about 14 cft. at both the temperatures. This value of gas produced corresponds with the values reported in literature. Bhaskaran (46) also reports 14 cuft of gas produced at a BOD loading of 0.188 lbs/cuft/day with 10 days detention time for distillary wastes. While for cheese wastes a value of 14-16 cuft for gas produced per lb. VM destroyed is obtained (46). Seth et el got a value of only 8 cft and 38% reduction in volatile solids at a detention time of 11 days for sewage sludge.

The gas produced per lb. of VM added also is quite close to the reported values. Algae gives a gas production of about 7.0 and about 8.0 cft at 35°C and 55°C respectively, while Dunstan and Hinden (43) reports a value of 9.33 cuft. at a loading of 0.05 lb/ft^3 per day with a detention time of 33 days.

All this goes to corroborate that algae is almost equally digestible as compared to the other wastes which have been subjected to anaerobic digestion.

The percentage of reduction in VS at both the temperatures for algae, which is 51 and 57%, is quite less as compared to the values achieved in other wastes (52,53,54,55). This low percentage of degradation of algae can be because of the ability of algae to withstand adverse conditions in the digesters. It is also possible that the living algae are immune to bacterial attack, so they are not easily subjected

to decomposition. The observation under microscope using a magnification of 430 clearly showed the presence of intact algal cells in the digester effluent indicating incomplete degradation in the digester. The species of algae observed are listed in table 11. The presence of complete cells in digester effluent hints that the cell wall is quite resistant and does not easily give way to bacterial attack.

4.3.2 Effect of Temperature on Digestibility

The results in table no.10 indicate higher percentage of degradation achieved at thermophilic temperature range. For algae the corresponding values are 51 and 57%. There is a net increase of 6-13% in degradation at various loadings. But the amount of gas yielded by one pound of organic matter degraded is about 14 cuft in both the cases. But higher values of daily gas production are recorded because of higher degradation.

The results indicate that the higher temperatures will not be economical as the net increase in digestibility is not very high because of high temperature.

4.3.3 Loading Rate

The loading rate was varied from 0.012 - 0.042 lbs/cuft-day and the optimum loading rate was obtained at 0.031 lbs/cuft-day. At this loading rate the gas yield is 7.0 cuft/lb. of VM fed at 35°C. As shown in Fig. 4.6

Table no.8 -

Algal digestion

Loading lbs/cft-day	Volatile matter in gms.	35°C Gas produced in ml.	35°C Gas produced in cft/lb volatile matter fed.	55°C Gas produced in ml.	55°C Gas produced in cft/lb. volatile matter fed.
0.0107	.258	90	5.6	105	6.13
0.0146	.352	130	5.92	145	6.6
0.0184	.443	160	5.79	185	6.7
0.0221	.532	210	6.32	225	6.78
0.0258	.620	265	6.86	310	8.03
0.0324	.78	340	7.0	390	8.03
0.0353	.85	340	6.42	415	7.85
0.040	.965	305	5.08	425	7.07

Table no. 9

Glucose Digestion

Loading lbs/cft-day	Volatile matter in gms.	35°C		55°C	
		Gas produced in ml.	Gas produced in cft/lb volatile matter fed.	Gas produced in ml.	Gas produced in cft/lb. volatile matter fed.
0.0125	.3	115	6.15	140	7.48
0.0166	.4	165	6.61	210	8.48
0.0208	.5	220	7.07	295	9.47
0.0250	.6	355	9.5	410	10.97
0.0291	.7	480	11.0	545	12.48
0.0331	.8	510	10.22	595	11.92
0.0374	.9	530	9.45	630	11.22
0.0416	1.0	560	8.97	665	11.06

Table no. 10

Gas yield per lb. of volatile matter destroyed

Loading lbs/cft-day	35°C % of vol. matter destroyed	35°C Gas produced cft./lb. of volatile matter destroyed	55°C % volatile matter destroyed	55°C Gas produced in cft per lb. of volatile matter destroyed
Glucose				
.0291	78.4	14.02	87.3	14.3
.0374	66.7	14.18	83.5	14.6
Algae				
.0324	51	13.71	57	14.1
.040	37.9	13.41	50.6	13.96

Table no. 11

Species of algae in the feed sludge and effluent from the digester

Feed Sludge	Digested Sludge
Arthospira	Arthospira
Chlorella	Chlorella
Navicula	Navicula
Anabaena	

The digesters with this loading fall under the category of conventional digesters, which have a loading rate of 0.03-0.04 lbs/cuft-day with 30 days detention time (39).

4.3.4 Effect of Harvesting Method Employed upon Digestibility of Algae

The harvesting methods basically can be divided into two categories. The one which give the harvested sludge without the addition of chemicals and the others which use chemicals for harvesting. So corresponding sludge obtained also either is free from external chemicals or it contains chemicals with it.

The algae harvested by autoflocculation or bioflocculation does not contain any additives and also no difficulty was encountered in its digestion.

While alum flocculated algae contained a large amount of chemicals with it. The sludge was found to have about 44% of total dry weight as alum. This sludge was not found to be digestible. There is an abrupt stoppage in the gas production. The digesters were first subjected to low concentrations of alum of 100 mg/l for acclimitizing the bacteria but even then alum flocculated algae was undigestible. This can be either because of Aluminum ion toxicity or potassium ion toxicity or it can be because of both of them. But McCarty reports that aluminum Salts are not toxic because of their low solubility (36). But potassium ion concentration of about 4500 mg/l is quite toxic (37).

Because of this observation algae harvested by using peptone and $KMnO_4$ as flocculent aids with alum were not tried for digestion.

Sodium aluminate flocculated algae was also not digestible. The reasons for this can also be same as for alum because firstly very large doses of this compound are needed for appreciable removal of algae and secondly this also contains sodium ions besides aluminum ions which are also toxic (37).

The harvesting by foam floatation yields a slurry of relatively dilute concentrations and algae harvested by this method were not tried in digesters as it was not possible to meet the requirements of algae for the digesters by a single column for foam floatation. However the algae harvested by this method should pose no problems for digestion, because neither the chemical doses required are large nor does the flocculent contain any toxic material as its constituent. The only important point is that the floatation column should be big enough to cater to the requirements of algae.

4.3.5 Nutrient Requirements

Algae do not need the addition of macro and micro-nutrients to the digester for microbial populations as it has all those essential elements in its protoplasm as previously mentioned in chapter II.

For glucose all the nutrients are to be supplied from external sources. For this solution 1 and solution 2, given in chapter III were added to the digesters.

4.3.6 pH of the Digester

The pH of the digester normally remained in the range 6.5 - 7.5 but whenever it went out of this range it was brought back to this range by suitable adjustments. The pH was adjusted by .1 N NaOH when it went below 6.5, on the other hand .1 N HCl was used to bring it down when it went above 7.5.

4.3.7 Sludge Appearance

The digested sludge from glucose digesters and algal digesters was quite different in physical characteristics. The glucose digester sludge was brownish in colour and it dewatered easily and quickly. While that of algal digesters was quite colloidal and dewatered poorly. These properties became still more prominent in the digester being run at $55^{\circ}C$.

Regarding the effect of high temperature on the properties like grannularity, odour and separatability of sludge different observations are made by different people. Golueke (56) reports that these properties became superior at high temperatures while Fischer and Green found the sludge digested at high temperature had poor dewatering qualities (28)

4.3.8 Solids Retention Time

Though hydraulic detention time was 30 days, but

because of recirculation of sludge the solids retention time was higher than 30 days. It was found to be 43 days for algae digesters. Because of poor settling properties a lot of sludge was wasted daily. MLSS, mixed liquor suspended solids, in the effluent from algal digesters were 25 ml/100 ml i.e. 250 ml/liter. Out of this 18 ml MLSS went in the effluent wasted daily. While for glucose digesters MLSS was 13 ml/100 ml i.e. 130 ml/litre and almost complete recirculation of this could be achieved, so sludge was wasted once a week.

4.3.9 Gas Composition

Carbon dioxide content of the digester was found to be 38% and the methane content to be about 60%. The rest of it is H_2S, H_2 and NH_3. The glucose digester gas had a higher percentage of CO_2. The value being nearly 50% and the methane content was also lower accordingly at about 50% with some amount of H_2S, H_2 NH_3. The daily variation in gas production is shown in Fig. 4.7.

GRAPH: LOADING VS GAS PRODUCTION IN ANAEROBIC DIGESTION

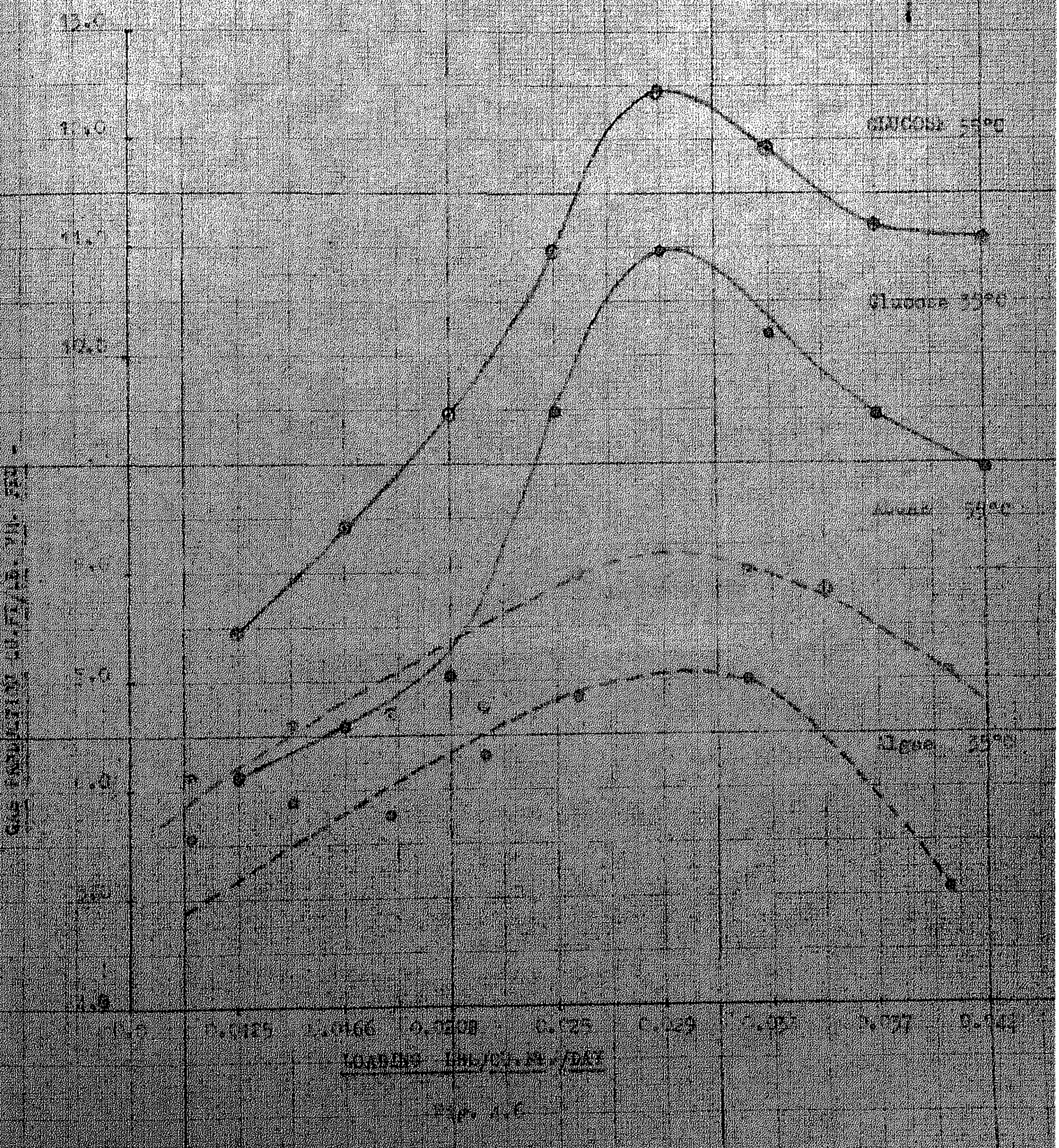


Fig. 4.6

Chapter 5

CONCLUSIONS

On the basis of this study following conclusions can be drawn:

1. Oxidation ponds when used as treatment units can serve as a copious source of algae for different modes of utilization.

2. Because of low surfactant dose requirements, less floatation time needed for high degree of removal, foam floatation seems to be quite effective mode for harvesting algae from oxidation pond effluent.

3. Alum is not very effective flocculating aid to Hexa decyl triammonium Bromide for foam floatation of algae.

4. Peptone and potassium permangnate are effective as coagulent aids to alum for coagulating algae.

5. Algae is easily digestible anaerobically at 35°C, like other organic wastes. The percentage of digestibility observed was about 51%.

6. A loading rate of 0.03 lbs/cft-day of algae at 30 days detention time yielded 7.0 cuft of gas per pound of VM fed in, while the gas production per pound of VM destroyed was about 14.0 cuft.

7. The digester gas contained about 60% methane. The net fuel value of methane is 963 Btu/cuft under standard conditions. So it can serve as a good domestic fuel.

8. Digestion of algae at thermophilic ranges did not give appreciable increase in digestion as compared to mesophilic ranges

9. Algae do not need external supply of nutrients for its digestion anaerobically.

10. Algae harvested by chemical coagulation using alum as coagulent is not digestible.

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